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ELECTROMAGNETIC RADIATION IN FRACTURE OF GLASS ARTICLES

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The results of experiments set up to register the electromagnetic radiation arising in fracture of glass bottles under the effect of a compressing load applied normally to the longitudinal axis are discussed.

One of the most significant properties of solid bodies is their capability to form and radiate electromagnetic and acoustic emission in the course of crack formation and fracture. Both types of emission have the same source, namely, the process of the appearance and growth of cracks in a solid body, and contain information on the mechanical properties of the solid body and its stressed-deformed state, as well as the processes taking place at the time of irradiation [1 – 6].

The present study is dedicated to the investigation of electromagnetic radiation (EMR) in crack formation and fracture of articles made of solid amorphous dielectrics, namely, of glass.

The experiments were performed on glass bottles, which are the most common product. The radiation emitted in fracture was studied in bottles of three different sizes (GOST 10117–91): bottles of type II-Sh-750 made of clear transparent glass; I-K-7000 bottles made of transparent green glass; bottles of type II-Sh-750 made of massive dark-green glass.

The experimental procedure involved uniaxial loading of the tested sample with synchronous registration of the EMR signals and the load from the start of loading to fracture of the article [7]. A specific feature of this method consists in contactless reception of the EMR signals, while the transducing antennas were placed at a distance of up to 100 mm from the loaded article.

The experiments were carried out on a laboratory bench which included a hydraulic press, electric antennas and amplifiers placed in an electric screen, and monitoring equipment. The loaded sample sheathed in a tarpaulin cover to avoid scattering of splinters was positioned between the press plates. A vertical compressing load was applied nor-

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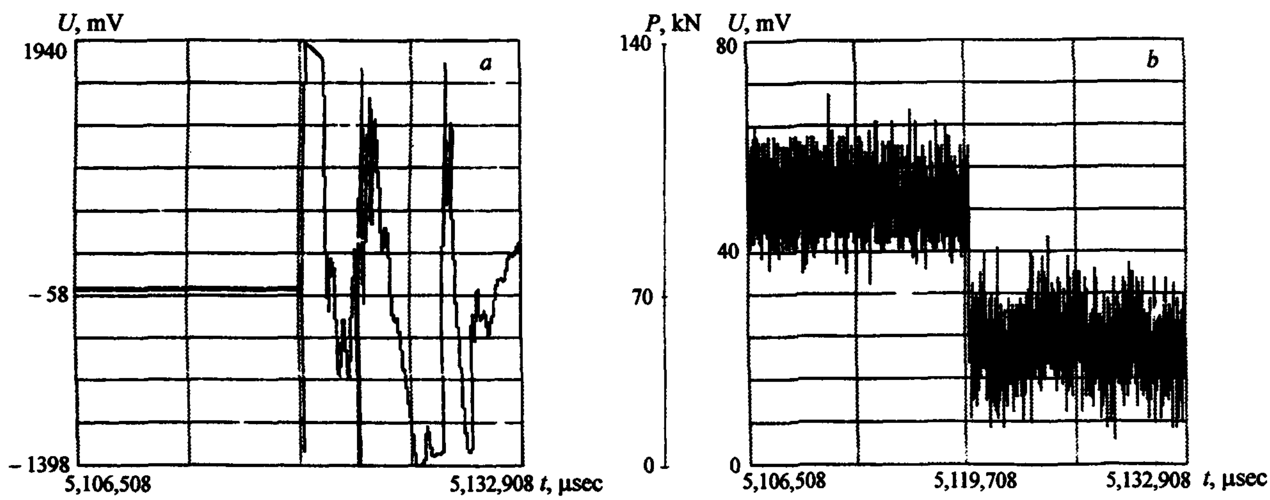

Fig. 1. Oscillograms of EMR (*a*) and load (*b*) in fracture of clear glass articles.

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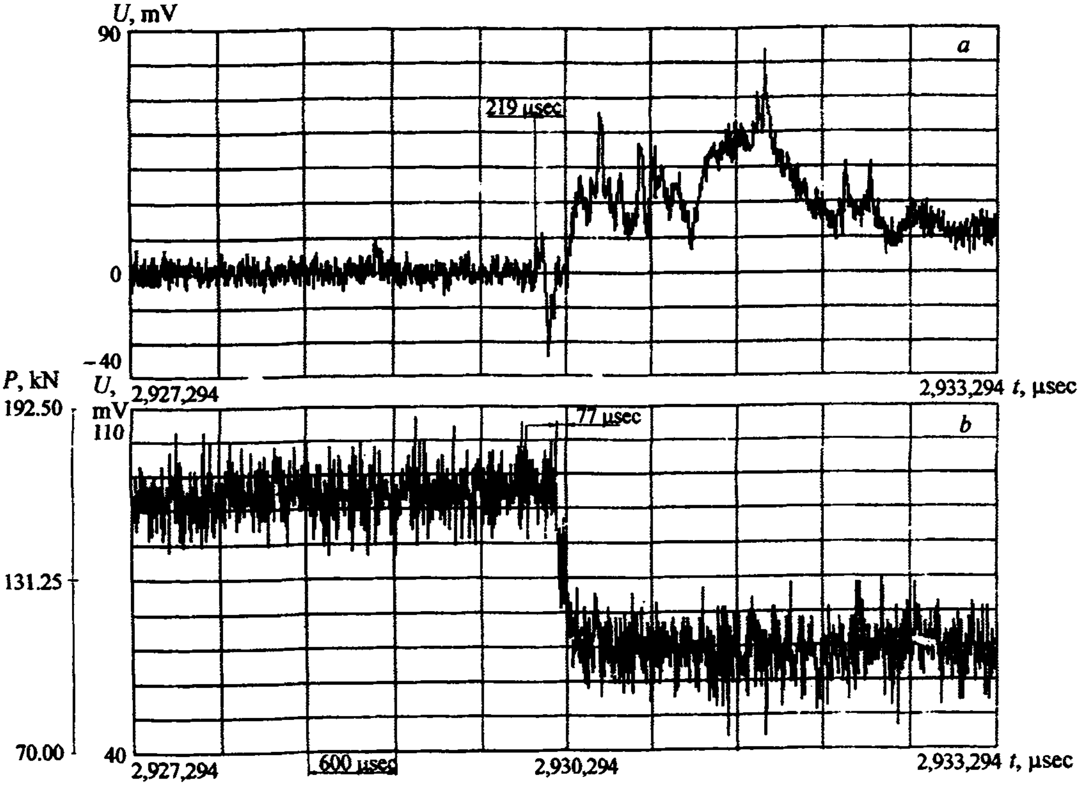

Fig. 2. Oscillograms of EMR (*a*) and load (*b*) in fracture of articles made of green glass.

mally to the longitudinal axis of the article. The present study considers the results of experiments performed on 11 articles.

The monitoring equipment consisted of a 486-DX-2 computer with a EISA bus and a 4-channel 12-digit analog-digital converter (ADC) in the form of an A-2000 board (produced by National Instruments). The load applied to the tested article was recorded with a force sensor designed as a steel cylinder with strain-gauge elements in a bridge circuit. The sensor was placed between the press plate and the loaded article. Two ADC channels were used: one recorded the load, and the other recorded the signal from the antenna. Continuous registration in each experiment lasted 8 sec. The system monitor displayed and simultaneously printed two oscillograms: the load and the EMR signal. The latter will be described using the example of the clear glass bottle.

Figure 1 shows the data registered in the first phase of loading that lasted 26,400 μsec after the start of loading. The start of loading corresponds to time $t = 5{,}106{,}508$ μsec, and the end of the experiment corresponds to $t = 5{,}186{,}241$ μsec.

The value of potential U received from the antenna and passing through the amplifier with gain factor $K = 100$ is shown on the ordinate of the EMR oscillogram. The ordinate of the load oscillogram represents the potential U received from the resistance strain gauge connected to the force sensor and included in the bridge circuit. In this case, the signal was first sent to the direct current amplifier and then to the PC input. The gain factor of the latter amplifier was $K = 1000$. The readings of the force sensor were converted to the load using the formula

$$P = NK_c,$$

where P is the load applied to the sample, kN; N is the reading on the ordinate, mV; $K_c = 1.75$ kN/mV is the calibration factor;

The EMR signal accompanying fracture is conventionally divided into three bursts (according to the time of passage through the zero potential). The signal duration of the first burst (Table 1) is $T_1 = 15{,}494$ μsec, for the second burst $T_2 = 11{,}452$ μsec; for the third burst $T_3 = 10{,}095$ μsec (absent in Table 1). The overall duration of the EMR signal is $\Sigma T_1 = 53{,}333$ μsec. The first burst contained $n_1 = 7$ single pulses, whose duration varied from several microseconds to about 2540 μsec (for the third and the fourth pulses). The second and the third bursts each contained two pulses. The maximum variation of the amplitude in the first burst ranged from $A_1^1 = -1398$ to $A_{max}^1 = +1940$ mV, and the maximum signal drop in the first burst was $U_{max}^1 = +3338$ mV and in the second burst from $A_1^2 = 1960$ mV to $A_{max}^2 = -2058$ mV with a maximum signal drop of $U_{max}^2 = 4018$ mV. The maximum potential drop of the entire signal was $U_A^1 = 4018$ mV.

TABLE 1

Article	Load drop of the moment of fracture	Anticipation of the first entry of EMR signal with respect to the moment of the load drop, μsec	First burst						Second burst						Signal parameters					
			T_1, μsec	A_1^1, mV	A_{max}^1, mV	T_1^1, μsec	T_{max}^1, μsec	n_1	T_2, μsec	A_1^2, mV	A_{max}^2, mV	T_1^2, μsec	T_{max}^2, μsec	n_2	m*	ΣT_i, μsec	U_{max}^1, mV	U_{max}^2, mV	U_{max}, mV	U_A^1, mV
Clear glass, diameter 86 mm	28	–	15,494	−1270	1940	δ**	1852	7	11,452	1960	−2058	11,452	δ	2	4	53,333	3208	4018	4018	1465
	19	–	4,042	−520	1020	δ	δ	5	5,389	−1000	−2000	5,888	δ	4	3	22,791	1875	1000	4050	1117
	43	63	2,296	236	1476	42	δ	11	29,200	600	–	δ	–	2	4	75,706	1574	700	3444	666
			1,260	45	74	63	252	12	–	175	–	320	–	1	4	1.176×10^5	146	175	240	146
Green glass, diameter 76 mm	23	50.5	19,200	84	–	2600	–	7	2,100	200	1930	δ	δ	9	2	–	310	3400	3400	310
	−24	51	11,000	−18	68	45	300	7	–	–	–	–	–	–	1	68,865	93	–	93	86
	32	142	10,400	60	168	60	δ	4	–	–	–	–	–	–	1	11,000	117	–	247	228
																10,400	–	–	–	–
Dark green massive glass, diameter 83 mm	200	–	13,460	−440	495	820	1076	5	20,190	1890	1890	5,384	–	9	3	–	1260	–	2790	1260
	65	42	6,057	100	1900	δ	δ	12	–	–	–	–	–	–		37,686	3238	–	1900	151
	29	201	2,355	390	−1080	δ	δ	5	8,076	150	2030	1,350	10,095	3	2	6,057	1470	2030	3110	1290
	130	42	4,410	470	−1120	441	1554	4	16,800	810	−422	8,463	8,400	3	2	10,431	1590	632	1590	1530
																21,210	–	–	–	–
Mathematical expectation	59.2	84.4	7,270	339.4	934.1	–	–	–	12,000	773.1	1770	–	–	–	–	35,000	1370	1700	–	–
Standard deviation	56.6	61.51	5,330	342.3	676.1	–	–	–	9,700	718.4	584	–	–	–	–	35,000	1100	1400	–	–
Excess***	0	0	0	0	0	–	–	–	0	0	0	–	–	–	–	0	0	0	–	–
Median	3.0	50.7	5,940	236	1050	–	–	–	8,100	405	1970	–	–	–	–	21,200	1470	1100	–	–
Covariance moment	–	–	–	5.195×10^5		–	–	–	–	–	–	–	–	–	–	-9.298×10^6		–	5.319×10^5	
Correlation coefficient	–	–	–	0.262		–	–	–	–	–	–	–	–	–	–	−0.254		–	0.626	

* Number of pulse bursts singled out in a signal.

** Time intervals for pulses whose right and left branches on the EMR oscillogram pulse merge into one line, and therefore, the duration of such a pulse cannot be estimated.

*** The excess in all cases is equal to zero, which shows that the respective distributions of random values of the experimental parameters are close to the normal distribution.

The total amplitude of the first pulse in the first burst was $U_A^1 = 1465$ mV, the amplitude of the first entry being 200 mV.

The EMR oscillograms and loads for the other 10 articles were considered following the same procedure (Table 1).

The EMR signal oscillogram and the load oscillogram recorded in loading of an article made of green glass are presented in Fig. 2. In this case, the load at the moment of fracture decreased by 32 mV (56 kN), or from 92 mV (1.6 kN) to 60 mV (1.09 kN). The beginning of loading in Fig. 2 corresponds to time $t = 2{,}927{,}294$. The fracture of the article occurred at $t = 2{,}930{,}217$ μsec. The entry of the first EMR pulse occurred 142 μsec ahead of the moment of fracture. In this case, the first pulse whose value exceeded the noise level was taken as the entry pulse of the EMR signal. The overall registration time amounted to 10 400 μsec (Table 1). No individual bursts were singled out in the EMR signal of this article. The maximum difference in the EMR signal pulses within the limits of the EMR oscillogram segment in Fig. 2 was $U_{max} = 117$ mV, however, for the overall signal $U_{max} = 247$ mV (Table 1).

The noise level can be estimated based on the EMR signal oscillograms in Figs. 1 and 2. In Fig. 1, the noise is characterized by a narrow strip before the appearance of the EMR signal, and the value of the highest positive amplitude of the signal exceeds the noise level by nearly 100 times. In Fig. 2, the noises oscillate from – 8 to + 12 mV. Accordingly, the EMR signal exceeds the noise level by approximately 6 times. The noise level in the course of the experiments was dependent on the internal noise of the instruments and on industrial noises, including the noise caused by operating radio stations.

Let us consider the experimental data presented in Table 1. All correlation coefficients are not equal to zero, hence, each pair of the experimental values consists of dependent random values. This is a significant result indicating that in spite of the variety of the parameters monitored in the experiments, all of them characterize the integral process of electromagnetic radiation inherent to glass as a specific structural material. Different EMR parameters characterize this process in different aspects.

Glass articles for special purposes require non-destructive testing of their integrity [6]. Electromagnetic radiation is a physical effect that can be conveniently used for flaw detection in glass articles.

From the performed experiments, the following conclusions can be drawn:

electromagnetic radiation emitted in crack formation and fracture is an inherent physical property of glass;

the experimental radiation parameters considered above are random values whose statistic parameters vary over a wide range;

electromagnetic radiation can be used for non-destructive testing of special glass articles in service.

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REFERENCES

1. P. V. Egorov, V. V. Ivanov, L. A. Kolpakova, and A. G. Pimonov, "Crack dynamics and electromagnetic radiation of loaded rocks," *Fizikotekh. Probl. Razrab. Polez. Iskop.*, No. 5, 20 – 27 (1988).
2. V. Ya. Lifshits, A. A. Semertchan, and A. T. Fomichev, "Acoustic emission and electromagnetic radiation in uniaxial compression," *DAN SSSR*, **255**(4), 821 – 829 (1980).
3. D. V. Alekseev and P. V. Egorov, "On the pulse shape of electromagnetic emission generated by a moving crack," *Fizikotekh. Probl. Razrab. Polez. Iskop.*, No. 6, 3 – 5 (1993).
4. V. A. Markov, "The study of electromagnetic radiation of rock samples with a screened magnetic antenna," *Fizikotekh. Probl. Razrab. Polez. Iskop.*, No. 2, 102 – 104 (1991).
5. M. V. Gokhberg, V. A. Morgunov, O. A. Pokhotelov, *Seismic Electromagnetic Phenomena* [in Russian], Nauka, Moscow (1988).
6. V. F. Gordeev, Yu. P. Malyshkov, L. I. Semkina, et al., "Radio wave flaw detector for quality control of silicate glass articles," *Steklo Keram.*, No. 8, 27 – 28 (1986).
7. *Testing Methods for Electromagnetic Radiation in Fracture of Rock Samples* [in Russian], Mining Institute (IGD) Siberian Branch, Novosibirsk (1989).